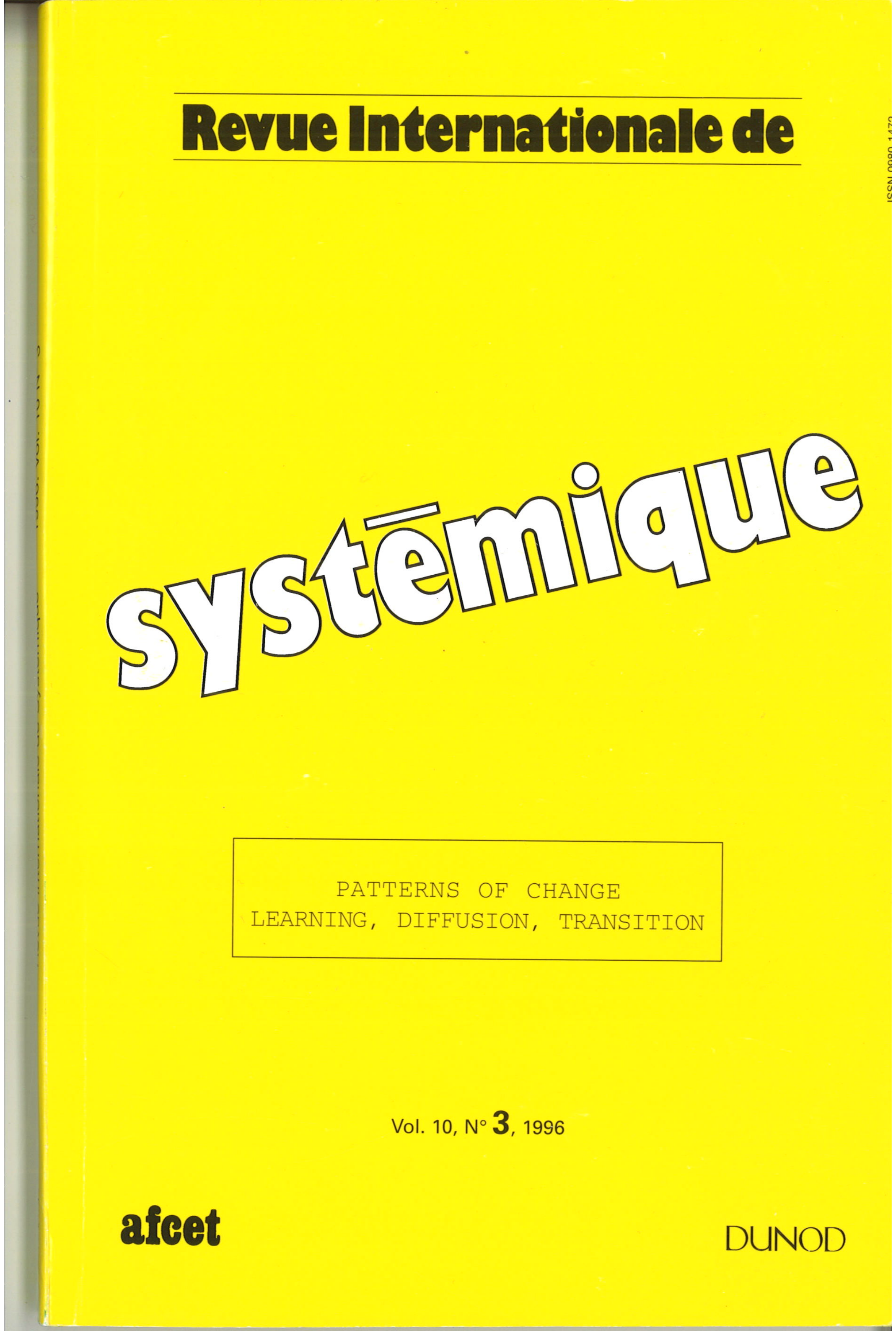

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THE ACCELERATION AND SLOWDOWN OF TECHNICAL PROGRESS IN THE US SINCE THE CIVIL WAR: THE TRANSITION BETWEEN TWO PARADIGMS*

Gérard DUMÉNIL [1] and Dominique LÉVY [2]

Abstract

This paper analyzes the basic features of technical and distributional changes in the US since the Civil War as the expression of the gradual emergence of a new paradigm, corresponding to a Managerial Revolution, and its replacement of the earlier organization inherited from the Industrial Revolution. A stochastic model of technical change of evolutionary inspiration is presented that accounts for the profiles of technology and distribution, within each paradigm. (Innovation is random, and new techniques are selected depending on their profitability). By averaging the two sectors of the productive system corresponding to each paradigm, it is possible to reproduce the historical trends for each variable. For example, the model explains why the productivity of capital and the profit rate displayed successively downward, upward, and downward trends over the three subperiods, 1869-1910, 1910-1950, and 1950-1992. Both the emergence and erosion of the favorable features of the intermediate period, 1910-1950, are explained by the diffusion of the new paradigm.

Résumé

Cette étude analyse les caractères fondamentaux des changements de la technique et de la répartition aux États-Unis depuis la Guerre de Sécession, comme l'expression de l'émergence progressive d'un nouveau paradigme, correspondant à une Révolution Managériale, et

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sa substitution à l'ancien paradigme hérité de la Révolution Industrielle. Un modèle du changement technique, d'inspiration évolutionniste, est introduit en vue de rendre compte du profil des transformations de la technique et de la répartition à l'intérieur de chaque paradigme (l'innovation est un processus stochastique, et les nouvelles techniques sont sélectionnées selon leur rentabilité). En faisant la moyenne des deux secteurs de l'économie correspondant aux deux paradigmes, il est possible de reproduire les tendances historiques des variables. Par exemple, le modèle explique pourquoi la productivité du capital et le taux de profit manifestent successivement des tendances à la baisse, à la hausse et à la baisse, au cours des trois périodes : 1869-1910, 1910-1950 et 1950-1992. La diffusion du nouveau paradigme rend compte, à la fois, de l'apparition puis de l'érosion des traits favorables de la période intermédiaire.

INTRODUCTION

The investigation of the historical profile of technology and distribution in the US economy, since the Civil War, reveals a periodization into three stages, corresponding by and large, to the late 19th century, the first half of the 20th century, and the post-1950s. There is an interesting similarity between the first and third periods, with slower growth rates of labor productivity and real wages, and a *declining* productivity of capital and profit rate. Conversely, and despite the paradoxical interruption of the Great Depression, the intermediate period –the first half of the century– combines several exceptionally favorable features: a stronger growth rate of labor productivity and real wages, and a *rising* productivity of capital and profit rate. This paper is a new attempt at the interpretation of these profiles to which we already devoted a number of studies [1].

The first and third periods can be characterized as two distinct *paradigms* (encompassing under this label, technology, management, related institutions, and their dynamics or, collectively, *technical progress*). The first paradigm is typical of mature capitalism, and was inherited from the English *Industrial Revolution*. The second paradigm is that of *Managerial Capitalism*. The revolution observed between the two paradigms relates to the *more efficient use of resources*, capital and labor. The intermediate period is interpreted as the progressive transition from the earlier to the more recent paradigm. As the new organization is gradually extended to all segments of the productive system, progress is manifested in the larger growth rates of labor productivity and the exceptional *rise* of the productivity of capital, paralleled by the simultaneous increase in the growth rate of real wages and a rising profit rate. During the third period, when the diffusion of the new paradigm was almost completed, the resurgence of earlier trends echoes the fact that technical progress is largely subject to the same rules under the two paradigms. A profile similar to that observed during the first period is reasserted, which we call a pattern *à la Marx*, since its combines the basic features described in Volume III of *Capital*, in particular a strongly rising capital-labor ratio (the composition of capital) and a declining profit rate (Marx, 1894, part three).

Each paradigm is described by a stochastic dynamical model of evolutionary inspiration, in which firms search for and select new techniques. In this respect, our approach is akin to that of Richard Nelson and Sidney Winter (Nelson and Winter, 1975, 1982). The purpose of this analysis is not only to argue for a more *realistic* approach to innovation and technical change than that provided by the production function –or to show how it is possible, within a nonconventional framework, *to relate factor prices and factor substitution*– but also to propose a simple and analytically manageable model.

The paper is composed of four main sections. Section I recalls stylized facts and makes explicit the interpretation in terms of transition between two paradigms outlined above. Section II presents the evolutionary model of technical change and its generalization to the case of two paradigms. Section III applies this model to the analysis of historical trends in the US. Section IV discusses the relationship of this analysis to earlier studies. (The mathematical treatments of the models and additional results can be found in Duménil and Lévy, 1995b.)

I. THE US ECONOMY SINCE THE CIVIL WAR: THE TRANSITION BETWEEN TWO PARADIGMS

Section I.1 documents the historical trends of the main variables accounting for technology and distribution since the Civil War and describes in some detail the basic features of the three stages. Section I.2 explains how we understand these movements as the transition between two distinct paradigms.

I.1. A periodization in three stages

The description of technical and distributional trends below is based on the conventional representation of production, in which two factors, labor and capital, are combined. Labor income corresponds to total labor compensation (including a correction for self-employed). "Profits" measure the entire excess of the Net National Product (NNP) over labor income. More precisely, the variables are defined as follows: (1) Labor productivity, Y/L, is the ratio of the NNP in constant dollars to the total number of hours worked, (2) The productivity of capital, Y/K, is the ratio of the NNP to the gross stock of fixed capital, both in constant dollars, (3) The capital-labor ratio, K/L, is defined as the gross stock of fixed capital in constant dollars divided by the number of hours worked, (4) Labor cost, w, is the hourly nominal wage (total compensation) divided by the deflator of the NNP, (5) The wage share, ω, is the ratio of labor income to the NNP, and (6) The profit rate, r, is obtained by dividing profits, *i.e.*, *the NNP minus total labor income*, by the *net stock of fixed capital*, both in current dollars [2].

Table 1 describes the average growth rates of labor productivity, the productivity of capital, the capital-labor ratio, the profit rate, the labor cost, and the average value of the share of wages, for three subperiods of approximately forty years and the entire period 1869-1992. An examination of these figures reveals a very similar pattern in three stages for the growth rates of each variable [3].

Table 1. Average annual growth rates (% per year) and average value of the wage share (%).

	1869-1910	1910-1950	1950-1992	*1869-1992*
$\rho(Y/L)$	1.22	2.33	1.48	*1.95*
$\rho(Y/K)$	−1.22	1.39	−0.88	*0.04*
$\rho(K/L)$	2.07	0.40	2.24	*1.48*
$\rho(w)$	1.46	2.33	1.48	*1.95*
$\rho(r)$	−1.66	1.40	−0.88	*0.05*
ω	65.7	68.5	65.2	*55.4*

The movements of labor productivity and labor cost are very similar. From 1869 to the turn of the century or early 20th century, these growth rates are smaller than the average for the entire period. Then the trend is steeper. Finally, a slowdown is observed, and the growth rates return to values close to those observed in the 19th century. The historical fluctuations of the productivity of capital, in figure 1 (—), and the profit rate, in figure 2 (—), are similar: declining during the first and third periods, and rising in between. The capital-labor ratio rises steeply during the first and third periods, and stagnates during the second period. The wage share is approximately constant, as could be gleaned from the similarity between the profiles of labor cost and labor productivity (since $\omega = w/(Y/L)$).

These observations clearly reveal the specificity of each period, the similarity between the first and third periods, as well as the exceptional features of the intermediate period. During this period, 1910-1950, the growth rates of labor productivity and wages were stronger than the average; the capital-labor ratio only grew slowly, and the trends of the profit rate and of the productivity of capital were *upward*. The coincidence of the larger growth rates of wages and of the rise in the profit rate emphasizes the very favorable character of this intermediate period. Conversely, we denote as periods *à la Marx* the first and third periods, where the profit rate *declines*, while the rate of growth of labor cost, as well as that of labor productivity, are below the average!

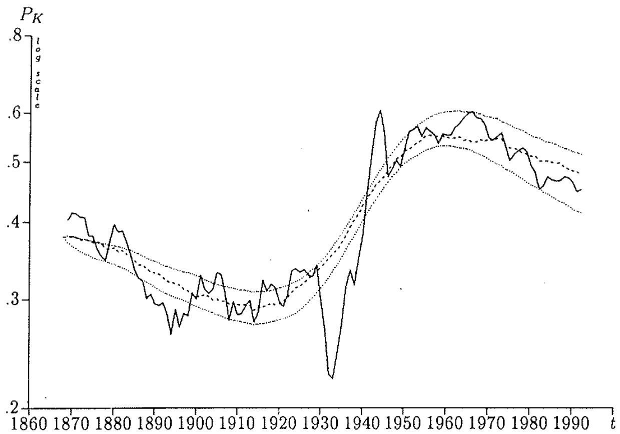

Figure 1. The productivity of capital.

In spite of the similar pattern in three stages observed for all variables, small differences are also evident. For example, the growth rate of the productivity of capital culminates in 1940, whereas the growth rate of labor productivity reaches its peak in 1951, that is eleven years later, simultaneously to the growth rate of labor cost (also in 1951) [4].

I.2. Two paradigms

We interpret these patterns as a manifestation of the existence of two distinct paradigms, characteristic of the first and third periods, and the gradual transition from the first to the second paradigm, during the intermediate period.

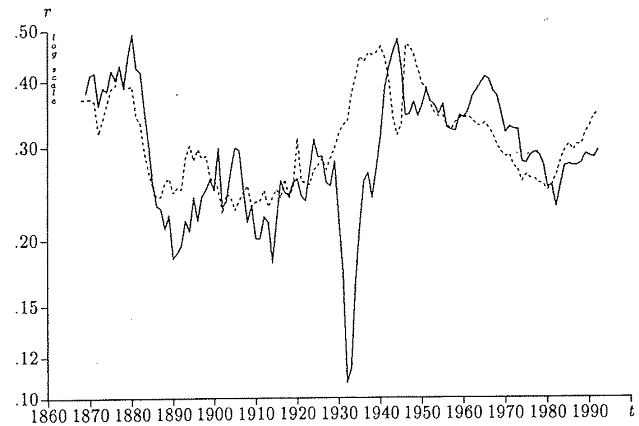

Figure 2. The profit rate.

Thus, our analysis combines two aspects of technical change: the transition between two paradigms, *i.e.*, the "revolutionary" component of technical change, and the dynamics of technical change within each paradigm, which accounts for the less dramatic component of technical change.

By *paradigm*, we mean a specific technology and its dynamics, *i.e.*, technical change. It is important to stress that technology must be understood in the very broad sense of the term, since it cannot be separated from a complex of social relations and institutions, such as the institutional framework of laws and regulations, the educational system, state involvement in research programs, etc., but also, at a more general level of analysis, relations of production and class patterns, inasmuch as they are related to technology and technical change [5].

The first paradigm is inherited from the Industrial Revolution in England, as described in particular by Marx in *Capital*. It is dominated by the factory system within industry (surrounded by more traditional organization within other sectors such as agriculture or services). The main feature of technical change is mechanization. The progress of labor productivity follows from the use of more and more sophisticated equipment, and the application of energy to production. The technical composition of capital, *i.e.*, the capital-labor ratio, grows rapidly, whereas labor productivity and real wages only grow slowly, and the productivity of capital and the profit rate decline. The typical social relation is that which antagonizes the capitalist owner to the productive worker.

The second paradigm corresponds to a "revolution" of a distinct type, a *revolution in management*: Firm management was transferred from traditional capitalist owners to a new class of managers, surrounded by numerous employees, *managerial and clerical personnel* (Duménil and Lévy, 1994b). Simultaneously, capitalists retreated to the financial sector of the economy.

An important literature, with often ambiguous motivations, has been devoted to this managerial revolution. Alfred Chandler (Chandler, 1977, 1990), for example, describes the rise of the large industrial corporation with its hierarchical management by salaried managers. He shows how this transition was performed in relation to new technical achievements and new industries, such as transportation and communications. During our intermediate period, this new organization infiltrated progressively all sectors of the economy, including trade and services.

The major characteristic of this new management can be summarized in one word, efficiency. Technology and all aspects of firm management were transformed, diminishing costs, and saving on fixed capital, inventories, liquidities, etc. The typical form of this new organization in the workshop is the assembly line, which, in a sense, can be described as a new shift toward *mechanization*. However, this equipment has been originally devised in order to ensure its continuous and intensive use. It simultaneously guarantees larger labor and capital productivities, instead of the traditional rise of labor productivity at the cost of a diminished productivity of capital (and does not result in a strongly increased capital-output ratio).

Note that the transfer of firm management to managerial and clerical personel does not imply that management is no longer targeted at the maximizing of profits. Quite the contrary, we believe that diminished profit rates in the late 19th century strongly stimulated this transformation, and that these new groups devoted their efforts to obtaining maximum profits. These efforts were successful and led to the rise of the profit rate during the first half of the 20th century. This restoration came as a bonanza after a period of significant decline of the profit rate.

Note that during the period of transition, technology and management are actually *heterogeneous*. Two segments coexist within the economy. There is no instantaneous switch to the new paradigm, simply because it is more profitable. This feature relates to the institutional facet of the metamorphosis, in which education, laws, etc. are involved. Even more fundamentally, relations of production are at issue: Corporate ownership must be substituted for individual ownership, property must be redistributed, a new class of managerial and clerical personel moves to the fore, etc.

Last, it must be stressed that the favorable features of our intermediate period mirror the *diffusion* of the new paradigm (from the origin, more efficient than the former paradigm), not *a priori* more favorable patterns of evolution (dynamics of technical change). It would be incorrect to relate the third stage to the exhaustion of the new paradigm; it actually reflects the *completion of the transition.*

A paradigm corresponds simultaneously to a given state of technology, at each point in time, and its law of evolution, *i.e.*, the rules governing technical change.

In order to analyse technical change within each paradigm, we use the model of evolutionary inspiration that we introduced in earlier studies (Duménil and Lévy, 1994d, 1995a). Innovation is a *random* and *local* process, expressing the outcome of R&D activities; firms select new techniques on the basis of a profitability criterion. Because of this reference to the profit rate, prices and, in particular, labor cost have an impact on technical change. A rising labor cost results in a rising capital-labor ratio. This dependency is important in the explanation of the profiles observed during our first and third periods, where labor productivity *rises* and the productivity of capital *declines*.

For simplicity, we assume that each paradigm follows its own law of evolution, *i.e.*, that the features of technical change within each paradigm are autonomous (in particular, the existence of the new, more efficient, paradigm does not accelerate the rhythm of technical in the older paradigm).

The model used in this paper is simpler than that presented in Duménil and Lévy, 1994d, since the productive system is considered globally, and little attention is paid to heterogeneity and disequilibrium (see section IV).

II. THE MODELING OF TECHNICAL CHANGE

The stochastic emergence of new techniques (innovation) and their selection based on a profitability criterion are described in section II.1. Then, section II.2 presents the general model in which two paradigms coexist, with particular emphasis on the central mechanism in this study, *viz.* the transition between two paradigms.

II.1. Innovation and selection (within a single paradigm)

Consider a very simple economy in which only one good is produced by a single firm. The production of one unit of this good uses A units of itself and

L units of labor as inputs. Thus, the productivity of capital is $P_K = 1/A$, and labor productivity is $P_L = 1/L$. Consider now a new technique (A_+, L_+). We define, a and l, the rates of saving on each input, by:

$$A_+ = A/(1+a) \qquad \text{and} \qquad L_+ = L/(1+l)$$

Variables a and l are also equal to the growth rates of the productivities of the two inputs:

$$\rho(P_K) = a \qquad \text{and} \qquad \rho(P_L) = l \qquad (1)$$

The comparison between the two techniques can be symbolically described as in panels (a) and (b) of diagram 1. A new technique is represented by a point, and the black dot (•) corresponds to the old technique. Within region [1], the new technique economizes on each input. Conversely, both inputs are increased within region [4]. Regions [2] and [3] described situations in which the economy on one input is obtained at the cost of an increased utilization of the other.

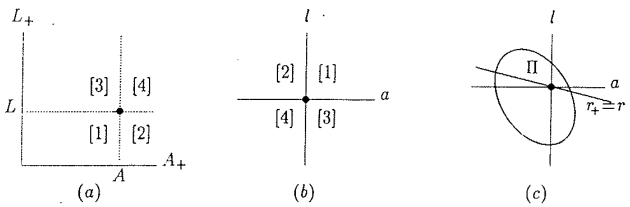

Diagram 1.

Innovation expresses the random outcome of R&D activities. When a project is initiated, it is not possible to predict its outcome. Firms search on the basis of the previously existing technique, and the size of innovation is limited (innovation is local). As shown in panel (c) of the diagram, we assume that innovation can be represented by a *probability law*, $\pi(a, l)$, whose support is bounded and denoted as the *innovation set*. It includes the existing technique.

New techniques within region [1] in diagram 1 save on each input, and will always be adopted, and all techniques in region [4] will be rejected. We will now discuss the decision to adopt a technique corresponding to regions [2] or [3], which saves on a single input at the cost of an increased utilization of the other.

The *profit rate* is the criterion in the selection of new techniques. If the profit rate, r_+, (computed with the same wage rate) of the new technique is larger than that of the previous one, r, the innovation is selected, and it is rejected if it is lower. The borderline between selected and rejected techniques, corresponding to the condition $r_+ = r$, can be represented by a downward sloping line crossing the origin in the plane (a, l) (see panel (c) in diagram 1). We denote this line as the *selection frontier*. Thus, only the new techniques which fall within the innovation set and above the selection frontier are selected. This region, II, will be called the *profitable innovation set*.

Using w to denote the exogenous *labor cost*, *i.e.*, the unit wage deflated by the price of the good (also called "wages" for short), the profit rate can be expressed as:

$$r = \frac{1 - Lw}{A} \tag{2}$$

Under the assumption that the innovation set is small, the new profit rate, r_+, can be developed linearly in the vicinity of the prevailing profit rate r:

$$r_+ = r\left(1 + \frac{\mu\, a + l}{\mu}\right) \tag{3}$$

In this equation, $\mu = (1 - \omega)/\omega$ is the ratio of profit to wages, with $\omega = Lw$ denoting the wage share. The equation of the selection frontier is $\mu\, a + l = 0$ (and its slope is μ).

This concludes the construction of the stochastic dynamical model for the two variables A and L (or P_K and P_L), with labor cost, w, as the only exogenous variable. On this basis, it is possible to generate "technical trajectories" within one paradigm. To this end, one only needs to specify the probability law which accounts for the emergence of new techniques, the initial values of A and L, and to follow the procedure indicated in this section, which allows for the derivation of A and L in $t + 1$ from their value in t [6]. Along such technical trajectories, any trend may prevail: capital productivity and the profit rate may rise or decline, labor productivity may grow rapidly or slowly, etc.

The model has two interesting properties. First, the value of the labor cost has an impact on the choice of new techniques and, therefore, on the substitution of capital for labor [7]. However, technology is a function, not only of the present value of wages, but of the entire sequence of wages, *i.e.*, it is *path-dependent*. Second, for a given growth rate of labor cost, technology converges to an asymptotic trajectory in which the wage share is given, as well as the growth rates of labor productivity, of the productivity of capital, and of the profit rate. Labor productivity grows at the same rate as labor

cost. The growth rates of the productivity of capital or profit rate are equal, and can be positive or negative.

The existence and stability of this asymptotic path do not imply that technology always gravitates around such a path. We believe that this situation is characteristic of a paradigm which has reached a form of "maturity". When a new paradigm is introduced, there is no reason to assume that such maturity has been attained.

II.2. The transition between two paradigms

If two paradigms exist, both of them can be represented using the model in the previous sections, with their own characteristic features (the probability law and the initial values of the productivities). The values of the variables for the total economy can be obtained by averaging for the two paradigms, weighting by the amounts of capital invested in each segment of the productive system.

We assume that the diffusion of the new paradigm throughout the entire productive system –from its mere appearance to its generalization and, therefore, the vanishing of the former paradigm– is steady, and can be represented by a declining function of time [8].

The transition can be depicted as in diagram 2, where each paradigm has reached its asymptotic trajectory. Each figure in this diagram depicts the two asymptotic trajectories (......) and the average for the total economy (—), for the productivity of capital (a), labor productivity (b), and the profit rate (c). The asymptotic trajectories of the two paradigms differ. In spite of the declining trends observed for both the asymptotic trajectories of the productivity of capital and the profit rate, the average for the total productive system can be rising during the transition period.

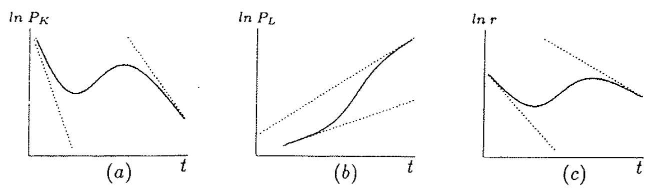

Diagram 2.

III. A MODEL FOR THE US

The model introduced in section II remains very general, and could be applied to several distinct problems. The present section applies this framework to the analysis of technical and distributional changes in the US economy since the Civil War. As shown in section III.1, an examination of the series suggests additional assumptions concerning the two paradigms. The reconstruction of the series is presented in section III.2. In this analysis, labor cost is still considered as an exogenous variable. Its modelling is, finally, introduced in section III.3.

III.1. A revolution in technology rather than in technical change

This section discusses the nature of the metamorphosis between the first and second paradigms. We locate the main difference between the two paradigms in the distinct initial values of the two variables, whereas, on the contrary, the features of technical change (the probability law) remained unchanged. In other words, the major metamorphosis brought about by the new paradigm concerns a new set of values of the two productivities and not the parameters governing technical change: a *revolution in the organization of production and in technology, rather than a revolution in technical change.* (More technically, there is a change in the levels, but not in the trends of the variables.)

This hypothesis is based on the striking similarity, observed in section I.1 (see table 1), between the trends prevailing during the first and third periods (late 19th century and second half of the 20th century). These two observations follow in a straightforward manner from the assumption that *the probability law is identical for the two paradigms.*

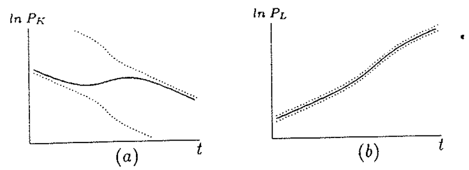

Diagram 3.

Assuming that the two paradigms remained in the vicinity of their asymptotic trajectories, and taking account of the fact that labor cost varied historically according to the pattern *Slower/Faster/Slower* (see table 1), two consequences for historical trends in the US clearly follow (see diagram 3). First, the *growth rates* of the productivity of capital in the two paradigms are equal. This is reflected in the fact that the two doted lines (......) in the diagram (a) are parallel. Second, the values of labor productivity are equal in the two paradigms, and the two doted lines are merged into a single one in the diagram (b). The rise of the productivity of capital (——) during the intermediate period is the effect of the transition from the first paradigm to the second. The rise of the growth rate of labor productivity (and the decrease of the growth rate of the capital-labor ratio) follows from the larger growth rate of labor cost and share of wages during this period.

III.2. Reconstruction

In order to reconstruct the variables, the model is used in simulation. A uniform probability distribution within a circle is chosen. At each period a new technique is determined randomly for the first paradigm. The profit rate of this technique is computed and compared to that obtained assuming that the previous technique is maintained. The technique yielding the largest profit rate is adopted. The procedure is initiated choosing values of the variables, A and L, which describe the technique in 1868. This procedure is repeated period after period, and a technical trajectory generated (the elementary period used in the model is not the year, but the month). The same procedure is then applied to the second paradigm with the same probability distribution. Finally, we compute the average values of P_K, P_L and r [9].

It is not too difficult to choose a set of parameters allowing for the reproduction of the two productivities and the profit rate. The results of this reconstruction are presented in figures 1 and 2 (- - - -), for P_K and r. In spite of the simple features of the model, these reconstructions are quite satisfactory.

In 1868, the ratio of the capital stock in the two paradigms is equal to 32 (*i.e.*, the capital stock in the new paradigm amounts to 3.3% of the total capital stock). This ratio declines rather fast, at an annual rate of 10.9%.

The initial values of the variables in 1868 are as follows:

First Paradigm: $A = 2.65$ *i.e.*, $P_K = 0.377$

$L = 0.369$ *i.e.*, $P_L = 2.71$

Second Paradigm: $A = 1.62$ *i.e.*, $P_K = 0.617$

$L = 0.116$ *i.e.*, $P_L = 8.60$

These figures emphasize the more efficient performances of the second paradigm whose productivities are considerably larger. One should be careful, however, concerning the precision of the above figures, since the productivities for the still embryonic second paradigm are not well defined for the first years [10].

The reconstruction of the variables results from a single random set of values of the variables. It is possible to estimate the confidence intervals for the estimations by varying only the stochastic variables, for the same set of parameters (including those characteristic of stochastic distributions). 1,000 such trajectories have been computed.

The doted lines (......) in figure 1 represent the upper and lower bounds within which 95% of the resulting sample runs lie. As can be expected all paths originate from the same initial value, and progressively the distance between the bounds increases with time. In 1992, an interval of approximately 24% is obtained for the productivity of capital. These observations show that the trajectories depend on the exact drawing, but that this dependency is limited and does not compromise the basic properties of the model.

III.3. The endogenous treatment of labor cost

The interpretation in the previous section provides two distinct explanations for the profile of the *productivity of capital* and *labor productivity* during the intermediate period. The variation of P_K mirrors the transition between the two paradigms, and that of P_L corresponds to the larger growth rate of labor cost. This difference relates to the still exogenous treatment of labor cost.

It is not the purpose of this study to analyze the determination of labor cost (or the real wage rate), which is a complex issue in which various time frames are involved. Concerning the point of view of the very long term in this study, we will adopt the model presented in Duménil and Lévy, 1993 (Section 15.4), in which the growth rate of the labor cost is expressed as a function of the growth rate of the profit rate and its value in each year:

$$\rho(w) = \beta_0 + \beta_1 \rho(1+r) + \beta_2 \ln(1+r)$$

This relationship expresses the view that increasing or larger profit rates are favorable to the rise of wages, and conversely for declining or lower profit rates. This link is quite obvious in the recent decades (since approximately the 1970s), when the downward trend of the pofit rate induced slower growth rates of the labor cost. The term $\beta_2 \ln(1+r)$ in the above equation accounts for the lag which can be observed in the variation of labor cost vis-à-vis that of the profit rate. For example, the larger growth rate of the labor cost during the 1960s were, to a certain extent, prolonged into the 1970s.

The model can be estimated including this new equation and, thus, treating labor cost endogenously. The results are as satisfactory as those obtained with the exogenous labor cost.

In this framework, the following conclusions are obtained. First, the transition between the two paradigms explains now *the two aspects* of the intermediate period. It accounts in a straightforward manner for the rise of the productivity of capital. It also indirectly explains the larger growth rate of labor productivity: The rising productivity of capital induces the rise of the profit rate, which, in turns, allows for the larger growth rate of the labor cost, which finally provokes the larger growth rates of labor productivity. Second, the fact that the growth rate of labor productivity reaches its maximum later than the productivity of capital, as noted at the end of section I.1, is explained by the lag of the labor cost on the profit rate. Third, it is the decline of the profit rate which explains the lower growth rates of labor productivity, and not the *productivity slowdown* which accounts for the decline of the profit rate.

IV. RELATIONSHIP TO EARLIER STUDIES

The model in section II is based on rather drastic assumptions. This option echoes the major emphasis in this study, which is placed on the *transition* between two paradigms, not on the *modeling of technical change within a single paradigm* as in previous studies (Duménil and Lévy, 1994d and 1995a). In particular, the model abstracts from all forms of heterogeneity and disequilibrium within the economy.

In Duménil and Lévy 1994d, we consider the three following sources of complexity, in a model in which a single paradigm is considered. A first source of heterogeneity is linked to the coexistence of *various vintages of fixed capital*, in which distinct techniques are embodied. The model in section II of the present paper describes the "average" technology by two input coefficients, and analyzes technical change as the variation with time of these coefficients. Actually, technology is, to a large extent, *putty-clay*, *i.e.*, once fixed capital has been installed, it is difficult to modify its technical features, and several vintages with different features exist simultaneously [11]. A second aspect of heterogeneity relates to the existence of *several goods and enterprises*. It is possible to generalize the model in this paper to the consideration of such diversity. (When a same good is produced by distinct producers, there is no need to assume a single price). Third, in the model in this paper, commodity markets are implicitly assumed to be in equilibrium, and productive capacities are supposed to be used at "normal" levels. The same approach to technical change can be embodied within a *general disequilibrium model*, in which decisions are made within disequilibrium, firms are price and quantity makers, supplies differ from demands, stocks of unsold commodities exist, capacity utilization rates differ from normal, etc. [12]. In this framework, where radical uncertainty prevails, behaviors are modeled in terms of adjustment to disequilibrium (and not maximizing). The overall conclusion of the investigation in Duménil and Lévy 1994d is that, from the point of view of the explanation of the macro profile of technical change and distribution, these additional sources of complexity are not essential.

In both Duménil and Lévy 1994d and 1995a, only a single paradigm is considered, and the historical profile of the variables is reproduced by *varying the parameters defining the innovation set*. The hypothesis in these earlier studies is that the difficulty to innovate was relaxed during the intermediate period, shifting the innovation set along the first bisector to the North-East. The present paper substitutes to this approach a different vision, in which two paradigms are distinguished, but with invariant features. The path and rapidity of technical change are now the effect of the different rhythms of accumulation in the two segments of the economy governed by the two-paradigms. This new interpretation has different advantages over the previous one. It moves one step further toward the endogenous treatment of technical change, in a more disaggregated model, and the vanishing of the favorable profile of the intermediate period is built in, "programmed" in a sense, since it corresponds to the completion of a transition and there is no notion of exogenous exhaustion of a paradigm. Finally, it is more in line with our understanding of the economic history of the US in general.

Notes and References

1. Duménil, Glick and Lévy, 1993; Duménil and Lévy, 1993, 1994*a* and 1995*a*.

2. Sources and the construction of the variables are presented in Duménil and Lévy, 1994*c*.

3. The notion of a perodization in three stages is not widespread. This is clearly revealed by the acknowledgement by Robert Gordon, in a recent paper, that he borrowed this idea from our work (see Gordon, 1993, footnote 1). Gordon used the expression one big wave to designate this profile. He analyzed the rise of the profit rate through World War II, and its relationship to the rise of capital productivity (Gordon, 1967). A number of early works identified the acceleration of labor productivity at the beginning of the 20th century (in particular, Kendrick, 1961); much research has been devoted to the analysis of the (labor) productivity slowdown during recent decades (see the survey of Denison, 1979).

4. In the dating of the maximum growth rates, we abstract from short-term fluctuations. More specifically, a trend line is determined using the Whittaker filter (see Hodrick and Prescott, 1980), and the year of maximum growth is that of the trend line. A parameter $\lambda = 1000$ is used in the filter, but these results are not very sensitive to this choice. (For $\lambda = 10000$, the maximum growth rate is obtained in 1938 instead of 1940 for the productivity of capital).

5. The use of the notion of paradigm, or related notions, is rather broad, but with various definitions. For example, Giovanni Dosi 1988 gives a rather narrow meaning to the notion of technological paradigm, which corresponds to a given equipment (the internal combustion engine) or industry (microelectronics). What we call a paradigm is closer to what Freeman and Perez 1988 call "technico-economic paradigm". In their analysis, each Kondratieff corresponds to such a paradigm. Another common point relates to the distinction that we make between technical change within a given paradigm and the shift to a new paradigm. This distinction echoes their hierarchy between incremental innovation, radical innovation, change of "technology system", and change of "technico-economic paradigm" (pp. 45-47).

6. Obviously, the issue of the endogenous nature of technical change in our model can be raised. The selection of new techniques is clearly endogenous, since it is based on profitability. The case of innovation is different. The probability law which governs innovation has been considered as given. There would, of course, be no objection to endogenizing this law.

7. The acknowledgement of this dependency of technical change on prices is also a component of Nelson's and Winter's analysis (Nelson and Winter, 1975, 1982).

8. In the model, we assume an exponential diminishing of the older paradigm. Other assumptions are also possible, for example, that the profitability differential accounts for the growth differential of the capital stocks in the two paradigms.

9. In the reconstruction of the profit rate, we do not attempt to reproduce the relative price of Gross National Product vis-à-vis capital, and the ratio of gross capital to net capital. These ratios vary in connection to the diminishing service life of fixed capital and the variations of accumution. Instead of equation 2, we use the formula, $N_1 N_2(1 - Lw)/A$, in which N_1 and N_2 correct for the two above effects and are determined empirically. (Note that this problem is not met in the reconstruction of the productivity of capital).

10. In addition, the values of labor productivity in 1868 are different, showing that the second paradigm has not reached its asymptotical trajectory yet.

11. See Duménil and Lévy 1994*a* for the details of the construction of a vintage model. This paper also discusses the issue of economic obsolescence and premature discards of older vintages.

12. This framework would allow for the discussion of the Schumpeterian relationship between the business cycle and technical change.

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